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FERTILIZER PROBLEMS AND ANALYSIS OF SOILS IN CALIFORNIA

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Several years ago a circular[2] was published dealing with certain general ideas concerning the chemical relations of plants and soils. Since that time additional investigations have been carried out, and it seems desirable to revise and to expand the previous discussion, especially because of the recent interest shown in soil problems.

In beginning the discussion, it is useful to emphasize once more the extreme complexity of the conditions which govern the growth of crops. The application of scientific methods to soil problems involves many difficulties not met with in the application of similar methods to industrial processes. Obviously, the latter can be controlled to a far greater degree than can the processes of plant growth as they occur under field conditions. Once the scientific and practical problems of a mechanical or chemical industry have been overcome, any given process may be repeated indefinitely with exactly predictable results. Such an achievement is seldom possible in the field of agriculture. Plants and soils exist in extraordinary variety, and both are subject to the variable and uncontrolled influence of climate. These statements would be true of any part of the world, but they have more than ordinary significance in California, because of its exceptional diversity of crops, soils, and moisture conditions. Notwithstanding the difficulties inherent in soil problems, real progress may be hoped for by persistent research, in field and laboratory, and only by this means.

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[2] Hoagland, D. R. Soil analysis and soil and plant interrelations. California Agr. Exp. Sta. Circ. 235:1–8. 1922.

CHEMICAL ELEMENTS OF THE SOIL ESSENTIAL TO PLANTS

The chief aspect of soil and plant relations to be dealt with in this circular concerns the processes by which crops take from the soil the mineral elements (plant foods) necessary for their growth.[3] The idea that only seven soil elements (potassium, phosphorus, calcium, magnesium, nitrogen, iron, and sulfur) are required by plants, is now known to be incorrect. The normal development of crops depends upon the ability of the soil to supply a conceivably large number of chemical elements, although only a few of these are needed by plants in more than minute quantity. It is doubtless true that such elements as manganese, boron, zinc, copper, etc., are present in nearly all soils in suitable amounts and forms, but various unexplained crop conditions, and certain field studies, lead us to suspect that this assumption may not be universally true. There are few, if any, practical suggestions to be made now along this line, but it is important to continue the investigations on elements not previously considered essential to plant growth. While recognizing that elements of the type just mentioned may be essential to plant growth in small amounts, it should also be kept in mind that the same elements can become toxic when present in too high a concentration. Boron is an example of this type of element.

CHEMICAL COMPOSITION OF THE SOIL MOISTURE AND THE FORMATION OF ACIDS IN THE SOIL

The present theories of plant nutrition are based on the assumption that plants can take up mineral elements only after the latter are dissolved in the soil moisture (soil solution). However, it is seldom true that there is present at any one time in the soil moisture sufficient amounts of all mineral elements needed by plants during the whole period of their growth. For example, during the season a crop may remove from the soil many times the amount of phosphate present in the soil moisture at the beginning of the season, even on the basis of the maximum volume of soil in which roots can develop. Availability becomes then partly, or perhaps chiefly, a question of the

[3] These mineral elements are usually referred to as ''plant foods,'' although this term is frequently used in connection with only three elements, namely, potassium, phosphorus, and nitrogen. In an accurate sense, these elements are not foods, but part of the raw material by virtue of which plants synthesize the actual foods. Water and carbonic acid gas are the other raw materials. In the present discussion, the terms potassium and potash may be considered as equivalent; likewise calcium and lime, magnesium and magnesia.

rates and concentrations at which essential elements contained in the solid portion of the soil can dissolve in the soil moisture. These rates and concentrations should be adequate to keep pace with the rates of intake by the plant, to the extent that no limitation in growth can occur because of a shortage in any one of the essential elements. A deficiency of one element will limit growth even if all other elements are present in abundance.

The solution of certain mineral elements necessary to plant growth depends primarily upon the production of acids in the soil, which in turn is dependent upon biological activities, that is, the activities of microorganisms and of root cells. The most important acids produced in this way are nitric, sulfuric, and carbonic. In most California soils these acids are neutralized by basic substances in the soil as fast as they come into existence. The salts thus formed dissolve in the soil moisture and become part of the nutrient medium of plants. To illustrate, bacterial action may bring about the production of nitrate (derived originally from nitrogen present in the organic matter of the soil) a soluble and available form of nitrogen, and at the same time calcium, magnesium or potassium will go into solution and become available to plants. Since these activities of microorganisms are primarily dependent upon the presence of organic matter in the soil, it is evident that organic matter is an important agent in making immediately available potassium, calcium, and magnesium. The great importance of organic matter in the soil for other reasons, such as the improvement of physical conditions, has been discussed on many occasions and these points need not be elaborated here.

The second means by which acids are formed in the soil is the excretion of carbonic acid by roots. The general opinion is that no other acid is excreted by roots, but this opinion is not necessarily conclusive in its application to all plants and to all conditions. In any event, the carbonic acid excretion by roots is considered by many investigators to be of great importance, because of the very intimate contact between fine roots, or root hairs, and colloidal soil particles. The dissolving of minerals, or their components, can take place in the closest possible proximity to the absorbing root surfaces. There is afforded, therefore, an especially favorable opportunity for the plant to have access to the mineral particles of the soil.

THE ABSORPTION OF ESSENTIAL ELEMENTS BY ROOTS

It also follows that the total area of root surface capable of absorbing mineral elements may determine in part the ability of a plant to obtain from the soil adequate quantities of some of the essential mineral elements. It is not merely a matter of what kind of soil a plant grows in, but also of how much soil. For this reason, as well as because of the water relations involved, emphasis is placed on the importance of maintaining conditions in the soil favorable for root growth. Among these conditions, suitable aeration and prevention of the formation of impermeable layers are often of extreme importance. Irrigation and cultivation practices are definitely related to the mineral nutrition of plants. Toxic substances, organic or inorganic, should be absent from the soil. The growth of roots is not influenced by soil conditions alone, but also by the environment around the top of the plant, where the food necessary for root growth is manufactured. Root growth, and consequently the ability of plants to obtain essential elements from the soil, may be modified by climatic conditions, fruit production, plant disease, insect injury, etc.

The roots of plants do not take up the soil moisture simply as it exists in the soil. Mineral elements may be removed at a faster or slower rate than the water in which these elements are dissolved. The plant should not be likened to a lamp wick sucking up the soil solution. Roots perform their functions normally only as a result of the activities of healthy living cells.

Different nutrients may be removed from solution at very different rates. Plants, therefore, have a ''selective'' action, but this does not mean that they possess the power to select only those substances required for their growth, rejecting all else. On the contrary, injurious substances may often be taken up by plants when such substances are present in the soil, and essential elements can be absorbed sometimes in quantities far greater than those needed for plant growth.

AVAILABILITY OF POTASSIUM AND PHOSPHATE

Assuming that the production of acids by microorganisms or by plant roots proceeds at a satisfactory rate, is it certain that potassium and phosphate will dissolve in the soil moisture in the amounts and proportions necessary for satisfactory crop growth? This depends upon the nature of the soil minerals. All minerals are soluble and available to some degree, however slight, but certain minerals have

a degree of solubility which makes them especially important in determining whether or not a soil can supply to a plant adequate amounts of potassium or phosphate.

First giving attention to the question of potassium, it is found that the amount of potassium easily dissolved by fairly dilute acids (such as ¼ per cent nitric acid) usually comprises only a small fraction of the total amount of potassium contained in the soil. The supply of this more easily dissolved potassium has an important bearing on the concentration of potassium capable of being maintained in the soil moisture, although the relation is not simple, nor always consistent. In general, it may be said that the degree of solubility of potassium is of much more importance than the total percentage of potassium present in the soil, but conceivably, a high percentage may not be without significance in some soils, if it implies a greater number of contacts between root surfaces and potassium minerals. The fineness of division of such minerals is important in this connection.

Experiments with a considerable number of California soils, carried on in Berkeley during the past twelve years, show that continuous cropping reduces the supply of available potassium, as determined by methods of the type described in the above paragraph. In some soils the amount of the reduction is of the same magnitude as that of the total potassium removed in the crop.

If a soil becomes depleted in the easily soluble forms of potassium, plants will have a relatively less favorable medium from which to absorb this element. But it does not necessarily follow that crops will always make unsatisfactory growth when the more soluble types of potassium are exhausted. Some crops may still find it possible to take out of the soil adequate amounts of this element for an indefinite period of time. The mechanism involved is only partly understood, but it may be repeated that solubility is only a relative term; all compounds of potassium are soluble to some degree. If the plant roots have a sufficiently large absorbing area, together with a sufficient activity in absorbing potassium from very dilute solutions, and if the growth cycle of the plant gives adequate time for absorption, a suitable adjustment may take place, even in soils which never contain in their soil moisture more than a slight concentration of potassium. Of course if this concentration falls too low, then it may happen that many useful plants will fail to thrive without proper fertilization of the soil with potassium. This latter condition is not infrequently reported to exist in soils of humid regions, but so far only a few instances of this extreme deficiency have been reported in California.

There is the additional very important idea to be considered, that different kinds of plants may differ in respect to the amounts of potassium required for the desired type of growth. Many agriculturists believe that plants producing large amounts of starch or sugar have a high potassium requirement, although the function of potassium in plant growth is by no means adequately understood as yet. Such plants are considered to give most satisfactory yields on soils containing relatively large amounts of potassium in easily soluble form. These ideas are chiefly based on experience in other parts of the world. It is not yet known whether or not crops of the type referred to would respond to potassium fertilization when grown on the majority of California soils. In a few cases the evidence is positive, and in others negative. At this point, it should be noted that many experiments indicate that it is possible to increase the percentage of potassium present in a plant by increasing the amount of available potassium in the soil through fertilizer additions. The increased amount of potassium contained in the crop, beyond a certain percentage, would be superfluous in that it would lead to no increase in growth or improvement of quality. Such excess absorption of an element is sometimes termed a "luxury consumption." The amount of potassium required by a crop may vary, depending on climatic conditions. Certain field experiments in England, and certain preliminary studies on plants grown under controlled conditions in California, suggest that the potassium requirements of plants may be altered by changes in light or temperature.

The total amounts of phosphorus present in ordinary soils are far smaller than the total amounts of potassium, but analogous considerations in regard to solubility apply. To give an illustration: two California soils were compared, each containing approximately the same total amount of phosphorus. Practically no phosphorus was dissolved from one soil by an acid of a certain strength, while from the other soil, treated in exactly the same way, more than half of the total phosphorus was dissolved. Many, probably most, plants of agricultural interest would make very poor growth in the first soil because of lack of available phosphorus. Various problems of this kind are now being actively studied in California and elsewhere. Present knowledge is entirely inadequate, but many instances could be cited in which field tests with phosphate fertilizers would be worth carrying out, especially with annual crops.

It is hoped that this discussion, although very incomplete, will nevertheless make it clear how complex the question of availability of potassium and phosphate is. Attention must be given, not only to

the soil type, but also to the type of crop, moisture, and other conditions in the soil favoring or inhibiting root growth, climatic environment, as well as to plant diseases and pests.

USE OF FERTILIZERS

Having sketched a few important general relations existing between crops and soils, certain views concerning fertilization will now be considered. In the first place, it is important to realize that some type of fertilization is required, sooner or later, for most crops under modern agricultural conditions. If we take a general average of experience throughout the world, we find that special concern is felt about maintaining available nitrogen in the soil. Crop responses to nitrogen applications, although not universal, are met with under the greatest possible variety of soil, crop, and climatic conditions.

Nitrogen is an element which can easily be lost from soils. When it is in the form of nitrate it is subject to leaching. But it is also possible to lose nitrogen in gaseous form. In this connection certain experiments made in Berkeley are of interest. Thirteen soils, from different parts of California, were studied over a period of years with reference to their total content of nitrogen. The soils were placed in a series of large containers, and one lot of each soil was cropped and one kept uncropped. At first the soils were maintained in a moist condition continuously, but without excess moisture or leaching. Under these conditions, in the course of five years, an important proportion of the total nitrogen in the soil was lost. Practically the same amounts were lost from the cropped and uncropped soils, which means that the loss of nitrogen was primarily the result of the activities of microorganisms, rather than removal of nitrogen by crops. On the other hand, under other moisture or cultural conditions, it is possible for a soil to gain nitrogen from the air in important amounts as a result of the activities of still other groups of organisms (other than legume organisms). Much further work must be accomplished before the nitrogen economy of the soil is sufficiently understood, but it is evident that losses of nitrogen may be great under some circumstances. This fact may help to explain why nitrogen fertilization is frequently of importance, whether by the growth of legumes or by addition of commercial forms of nitrogen. In connection with all questions relating to nitrogen, it is of the utmost importance to consider the activities of the soil microorganisms and the possible influence of irrigation practice and additions of organic matter on these activities.

To understand correctly the fertilization of a soil with phosphate or potassium requires recognition of the fact that these substances react chemically with the soil. The point of interest, as far as crop growth is concerned, is the resultant condition of the soil after fertilizers or other amendments are added. The same fertilizer will produce different effects, in greater or lesser degree, in every different soil. Sometimes reference is made to the use of "balanced fertilizers." The balance which is important is not in the fertilizers, but in the soil after the fertilizer has been added and has reacted with the soil. A fertilizer cannot, in any accurate sense, be compared with a "balanced ration" for an animal. The feeding of animals and the absorbing of mineral elements by plants are totally different in nature.

Potassium (potash) reacts in soils chiefly with certain colloidal mineral substances, which are in some degree (but only partly) analogous to artificial zeolites such as are used in softening water. In this reaction there occurs an "exchange of bases."[4] For example, some of the potassium added may go out of solution, and calcium (lime) or magnesium (magnesia) enter into solution to take the place of the potassium which is "fixed." Not infrequently, in soils of fairly heavy character, nearly all of the potassium added in an ordinary fertilizer application is fixed in this way, liberating other bases, especially calcium and magnesium.

The phenomenon referred to above is of great interest in connection with the fertilization of fruit trees, for the reason that in many soils most of the potassium added may be fixed in a surface zone, out of reach of much of the root system. Soils in which availability of potassium is low sometimes have especially high fixing power, although this statement would not usually apply to sandy soils. Therefore, in soils of high fixing power it may be especially difficult to alter the condition of the soil in contact with the roots developed below the surface zone. Of course, it is not impossible that the required changes might be brought about in some instances by using very large amounts of fertilizer, applied at one time, or by using smaller amounts over very long periods of time. In some cases the total amounts required might be far greater than those used in ordinary commercial practice. Interesting experiments are now being carried on by several investigators to determine whether some of the difficulties may be overcome

[4] This general phenomenon has been studied extensively by the Laboratory of Agricultural Chemistry, at Riverside. Those who are interested in a fuller development of the discussion should consult the publications issued from this Laboratory. Some of these studies are available as bulletins and Hilgardia from the Agricultural Experiment Station, Berkeley, while others have appeared only in scientific journals and usually are available only in libraries.

by new methods of applying fertilizers, should necessity arise for fertilizing deep-rooted plants with potassium or phosphate.

Although the fixation of potassium may prevent this element from becoming available to roots in the deeper layers of the soil, nevertheless, in many soils the ''fixed'' potassium can be absorbed by plants to a large extent, when roots develop directly in contact with the soil particles on which the fixation occurs. This has been found to be true of certain California soils of high fixing power for potassium, in experiments with plants such as wheat, barley, tomatoes, beets, etc. Presumably the fixation of potassium in such cases is not so firm as to prevent it from dissolving gradually at the zones of contact between roots and soil particles. The plant is an active agent in the process, because of carbonic or other acids which may be excreted by roots, and because of the rapid removal of potassium from the soil moisture by the growing plant. The latter action makes it possible for new supplies of potassium to enter into solution continuously as long as a suitable source of potassium remains in the solid portion of the soil. It is clear from all these considerations that the location of root systems is a very important question in potassium fertilization.

Phosphate, as well as potassium, when added to a soil may undergo chemical change, although the chemical reactions involved are different from those applying to potassium. It is possible for phosphate easily soluble in water before addition to the soil to become much less soluble afterwards. Consequently, in this case, also, it may become very difficult to change the soil condition below the zone in which the phosphate fertilizer is mixed with the soil.

Just as with potassium, the fixation of phosphate may not prevent plants from absorbing phosphate added in a fertilizer, provided again, that sufficient root development occurs in that portion of the soil to which the phosphate is added. A striking example of this is found in certain California soils of high ''fixing'' power, in which some crops make hardly any growth because of the insolubility of the phosphate naturally present. Yet the addition of certain soluble phosphates to these particular soils has an extremely beneficial effect on various surface-rooted crops. The manner in which plant roots absorb phosphate in such cases is only very slightly understood as yet, but no doubt stress can be placed on the intimate contact between roots and soil particles, and on the finely divided nature of the compounds formed when added phosphate is precipitated in the soil. Plant roots coming in contact with such particles, and giving off carbonic acid, may be able to dissolve the necessary amounts of phosphate. Probably

in the case of some fertilizers, and with certain methods of application, there may occur direct contacts between roots and particles of fertilizer, before the latter undergo extensive change.

In some soils the particular form of phosphate used may be important. There is evidence that it is possible for a part of the added phosphate to undergo, gradually, such strong fixation that it becomes unavailable to plants, even when root contact takes place. This loss of availability possibly may be more rapid with some forms of phosphate than with others. These remarks do not apply with equal force to all types of soil, and furthermore, the method of applying the phosphate fertilizer is of importance, and modifies any comparisons of different types of phosphate fertilizers. Some investigators believe that potassium, when added to certain soils, also may slowly undergo changes rendering it unavailable to plants, notwithstanding proper contacts between soil and roots. In the California soils investigated, it does not appear that added potassium can become unavailable to nearly the same extent as phosphate does in certain types of soil, including some found in California.

From the foregoing considerations, it is evident that in the case of surface-rooted crops it is possible to modify, at least for a time, the nutrient condition of a soil with respect to phosphate and potassium by the use of suitable fertilizers, applied in reasonable amounts, although larger quantities may be needed on some soils than is in accord with current practice. But the practical question arises, how generally phosphate and potassium, as well as nitrogen, must be used. Concerning this point no general statement can be made. The kind of soil, its previous agricultural history, the amount of potassium or phosphate already removed by crops, the crop to be grown, and the climate, all enter into the equation. Over any given period of years, many soils may maintain their fertility with the addition of only one or two of the above named elements, for the reason that the remaining elements are still supplied in sufficient abundance by the minerals already present in the soil. Under these circumstances, a "balanced" condition for crop growth might be brought about in a soil by the simple addition of nitrogen, and perhaps organic matter, in appropriate form.

The remarks which have just been made are in no way inconsistent with recognition of the fact that continuous and intensive cropping in general tends to lower the amount of easily dissolved phosphate or potassium, even in soils of high initial fertility, such as are often found in California. The question which has to be asked for each soil is: Has a critical point been reached, or will it be reached soon, or is a state

of depletion still far in the future? The answer to this question will be modified in accordance with the nature of the crop as well as the soil, since, as already indicated, there is a possibility that some crops (including, perhaps, many types of fruit trees) under otherwise favorable conditions, may be able to absorb sufficient potassium or phosphate from slightly soluble compounds, which are present in most soils in amounts which are large relative to crop withdrawals. This is especially true of potassium.

However these questions may be decided for particular cases, the general statement can be made that serious soil difficulties will arise in course of time under conditions of exhaustive cropping, unless provision is made for additions to the soil, whether by means of cover crops, animal manure, nitrogen fertilizers, or other commercial fertilizers, or by some combination of these materials. Both the chemical and physical state of the soil are involved. The maintenance of fertility will not usually be automatic, although certain California soils seem to be initially so fertile that marked effects of exhaustion may be very long delayed.

COVER CROPS AND ROTATION OF CROPS

The turning under of cover crops may tend to build up the soil reserve of easily available potassium and phosphate. This action is explained by the gradual accumulation in the growing plants of phosphate and potassium derived from very slightly soluble compounds present in the soil. Later, the entire amounts accumulated in the plant tissues, when returned to the soil, may remain in an easily available form for other crops. How important these changes are in California soils is not yet known. It should be remembered in this connection that plants grown on soils containing very small amounts of available potassium or phosphate are likely to have relatively low percentages of these elements present in their tissues. Consequently, there would be this limitation to the possible increase in availability of potassium and phosphate through the use of cover crops.

In many parts of the world where agricultural experience is of long duration, it has been found that the practice of continuously growing one crop often gives very unfavorable results. In such cases, suitable rotations of crops, including legumes, frequently accompanied by the use of phosphate or other fertilizers, have been worked out through long periods of field experience. The desirability of crop rotation is not necessarily to be ascribed merely to the maintenance of nitrogen content in the soil, or possible differences in the abilities

of different crops to utilize relatively insoluble potassium or phosphate, however important these factors may be. Some investigators emphasize the development of injurious soil microorganisms, plant diseases, or toxicity caused by residues of crops. There are cases in which it has been possible to grow the same crop for many years, when animal manure, or commercial fertilizers, or both, have been applied in suitable amounts, but it appears that in general crop rotation should be strongly emphasized. Recent opinion is to the effect that insufficient attention has been given to crop rotation in California.

USE OF ANIMAL MANURE

In considering the matter of potassium or phosphate fertilization, it is essential to recall that considerable quantities of these nutrients, and especially of potassium, are added to the soil when large amounts of animal manure are systematically applied. From earliest times, the observation has been made that the use of animal manure nearly always produces highly favorable effects on the growth of plants. This question has been under careful study at the Rothamstead Experimental Station, England, for over seventy years. It has been found that in the case of wheat, farmyard manure applied at the rate of 14 tons per acre annually gives higher yields than does artificial fertilizers containing similar amounts of nutrients. From these, and from many other experiments and observations, it appears that the beneficial effects of manure are not always limited to its content of nutrient elements. The possible improvement of the physical condition of the soil is a very important matter. The improvement of the soil as a medium for desirable microorganisms must be given consideration. The use of manure may increase the amount of nitrogen fixed from the air, according to some investigations. Other beneficial effects may be brought about which are not clearly understood at the present time.

Although the use of manure may largely solve a problem of soil fertility for certain crops or districts, it is obvious that this is not a universal solution of soil problems. Adequate quantities of manure frequently are not available, and furthermore, manure produced on one soil and applied to another, still leaves open a question of fertilization of the soil from which the nutrients contained in the manure were withdrawn. It cannot be denied that under many modern agricultural conditions, commercial fertilizers of one type or another must play an ultimately indispensable rôle, subject to such limitations as this circular attempts to describe.

FERTILIZATION AND QUALITY OF CROP

Much discussion has taken place concerning the possible influence of potassium or phosphate fertilization on quality of crop as distinct from yield. It seems evident that the quality of certain types of crops may be influenced by fertilizer applications under some soil and climatic conditions. The improvement or change of quality occurs primarily in soils which are initially very deficient in ability to supply one or more nutrient elements. Many of the reports dealing with the effects of fertilizers on quality of crops are based on experiments carried out under soil and climatic conditions different from those found in most parts of California.

Some observations have been made indicating that fertilizers applied to deficient soils may alter the rate of growth or time of maturity of various crops. For example, phosphate, when applied to such slightly fertile soils, may accelerate root development and promote earlier tillering and grain formation in cereals. The same fertilizers may hasten the early growth and time of blossoming of tomatoes. With plants of these types, the presence of adequate amounts of available phosphate in the soil during the early stages of plant growth seems to be very important. The addition of potassium to a soil highly deficient in available potassium tends to produce plumper seed in the case of cereals. It is important to recall that none of the effects just mentioned may be observed if the potassium or phosphate already present in the soil is sufficiently available.

With fruit trees, it is exceedingly difficult to obtain convincing results concerning quality, when both the fertilized and unfertilized trees are reasonably normal. Most reports by investigators are negative or inconclusive. There is evidence, however, that some types of fruit trees can become diseased on *certain types* of soil as a result of deficiencies (for example, deficiencies of potassium) or toxicities present in the soil. In any attempt to correct such conditions, the statement already made should be borne in mind, to the effect that it may be very difficult and expensive to increase the amounts of available potassium or phosphate in the deeper root zones, at least by the customary methods of fertilizer application. Also, cases have arisen where favorable effects are obtained only by the use of such substances as iron sulfate and copper sulfate, rather than ordinary fertilizers. Problems of this type are now under systematic investigations by various Divisions of the Experiment Station. Information of progress made in the districts concerned may be obtained from the

appropriate members of the Experiment Station, or from the farm advisor.

Numerous field observations have been cited by different investigators which are believed to show that potassium renders plants more resistant to certain diseases, especially those caused by fungi. The possible relation of fertilization with phosphate or potassium to some types of plant diseases is a subject of great interest and importance. Unfortunately, the investigational work is extremely difficult, and we do not now have any adequate working knowledge. It is not unreasonable to suppose that with some, but by no means all diseases, plants are more likely to suffer serious injury when in a state of malnutrition. A marked deficiency of an essential element leads to an abnormal change in the organic composition of plant tissues.

ACID AND ALKALINE SOILS

Many inquiries are made concerning the acidity or alkalinity of soils. All soils must be either neutral, acid, or alkaline. By a neutral reaction is meant one which is exactly the same as that of absolutely pure water, used as a standard. The degrees of acidity or alkalinity are designated by the symbol pH.[5] Markedly acid soils are common in some regions, but they are comparatively rare in California. Soils of this character may sometimes be found in those areas of the state having a very high rainfall. Highly alkaline soils sometimes occur, but a discussion of these soils would make necessary a consideration of "alkali" conditions, which are discussed in other publications. The reaction of a soil is subject to change resulting from the action of substances added to the soil. Thus, sulfate of ammonia may tend to increase acidity, and nitrate of soda to lessen acidity, or to increase alkalinity. Sulfur tends to increase acidity, and lime to decrease it. It is difficult by the use of ordinary fertilizers to bring about appreciable changes in the reaction of a soil within a limited period of time, unless the soil is of a light or sandy character and has a low resistance to change of reaction through the addition of acid or alkaline materials.

With most plants of agricultural interest, a considerable latitude in soil reaction is consistent with good growth. A slightly acid soil is not necessarily unproductive. For example, certain rather acid peat

[5] With this system, pH 7 means a neutral reaction; values below 7 indicate acidity, and values above 7, alkalinity. A soil of pH 5 is decidedly acid, one of pH 9 decidedly alkaline. A great many soils in this state have reactions not far from the neutral point.

soils, when properly fertilized, are very productive. It is necessary to emphasize the point that the reaction or "pH" of a soil is merely *one* factor influencing growth, and that the determination of this value, important as it is at times, seldom or never should be relied on as a guide to understanding soil conditions, without a suitable knowledge of other factors interrelated with the reaction.

SOIL ANALYSIS

It is hoped that this presentation of the complexity of soil problems has made it clear that routine chemical analyses cannot often determine the adaptability of soils to crops, or the best method of fertilization. It is true that special investigations on soils, and the understanding of general principles, cannot progress without the use of chemical methods, but really adequate studies are costly. They can be carried out by the Experiment Station only in selected cases, to obtain knowledge of general relations, or to assist in the planning or interpretation of field experiments. The validity of any interpretation of chemical data must rest finally on the results of experiments with plants. Even if there were now available assured methods of obtaining and interpreting chemical data on soils in terms of crop growth, there would still remain the question of securing representative samples of soil for examination. The most uniform field in appearance may, in fact, contain numerous soil variations, so that often it is difficult to obtain samples which may be considered to reflect an average condition. In addition, there arises the question of the relative importance of samples of soil taken from different depths, which would vary with the crop, physical character of the soil, irrigation practice, etc.

If it be desired to consider the examination of soils by the method of water extraction, it should be recalled that the water soluble portion of a soil does not have a constant composition. In fact, the composition may vary from day to day. The rapid growth of certain crops may bring about a temporary depletion of substances dissolved in the soil water, even with the most fertile soils. Therefore, if methods of this type are to be employed, it is necessary to recognize that different results may be obtained when samples are taken at different times of the year. The investigations of recent years emphasize the importance of including studies on the solid portion of the soil, in order to understand its ability to continue supplying nutrients to the soil moisture.

Occasionally soils are found on which comparatively simple chemical tests may strongly suggest a deficiency, but such soils are often extreme enough in character so that the general nature of the deficiency is already recognized by practical observations. Any possible future development tending toward a more general application of chemical tests to soils must be the result of comprehensive controlled experiments with different crops, as well as of a more critical study of field experience than it has yet been possible to make in most parts of California.

Soil and plants are altogether too complex to permit of any easy or quick method of determining the best methods of soil treatment. There must be a patient accumulation of knowledge gained in several ways: (*a*) by continued investigation of basic relations which enter into soil problems everywhere; (*b*) by further practical observation and experience; (*c*) by very carefully conducted and long continued local field tests or experiments, accompanied when necessary by special types of chemical and physiological studies. Immediate practical steps to be taken cannot be decided upon without reference to local conditions, and none of the statements contained in this circular should be construed as a specific recommendation for any kind of soil treatment. Those who desire to avail themselves of the services of the College of Agriculture should, in the first instance, consult the farm advisor of their county, or an extension specialist. These representatives of the institution have available to them the information gained in the investigations of the Experiment Station, to be utilized as may be possible with due reference to local conditions.

Other circulars, or mimeographed sheets, may be obtained from the office of the county farm advisor, or from the Division of Plant Nutrition, University of California, explaining the type of service which the College of Agriculture is capable of rendering in connection with soil problems.

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